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Processing Alternatives for Millstream Potassium/Magnesium Project, New Brunswick

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Processing Alternatives for Millstream Potassium / Magnesium Project New Brunswick

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SECTION 1.0 EXECUTIVE SUMMARY

This report presents a literature review of process technologies that are capable of producing potassium and magnesium products from sylvinite and/or carnallite brine. The project is based on the development of the Millstream property using solution mining techniques to produce a concentrated brine. Although the project objectives were not specific to a brine composition or product market, commercially viable process technologies were identified for brines containing saturated concentrations of sodium, potassium and magnesium chlorides.

Various companies located in Germany have specialized in the design and operation of solution mining and treatment of brines for both potassium and magnesium chemical/fertilizer markets. The development of evaporation/crystallization unit operations for the treatment of sylvinite/carnallite brine is considered a commercially proven process technology. Specialized leaching technologies known as "selective leaching" are also used to selectively extract either magnesium or potassium, to improve on the commercial viability of processing sylvinite/carnallite ores.

Although solution mining has been known to be cost competitive with conventional ore extraction mining techniques, the energy consumption for the treatment of brines by steam heated evaporators/crystallizers may be regarded as a limitation to the development of the Millstream property. However, the use of combined cycle gas turbines, alkali precipitation and/or solvent extraction process technologies may be considered as economically viable development alternatives. An economic and technical assessment of these technologies is recommended to quantify the feasibility of solution mining/brine treatment, specific to the Millstream property.

SECTION 1.0 RÉSUMÉ

Le présent rapport livre une analyse documentaire de techniques minéralurgiques permettant d'obtenir des produits à base de potassium et de magnésium à partir de saumure de sylvinite ou de carnallite. Le projet s'appuie sur la mise en valeur de la concess. n de Millstream au moyen de techniques d'extraction par solution pour la production d'une saumure concentrée. Même si le projet ne visait pas spécifiquement un marché de produits ni une composition de saumure donnés, on a mis au point des techniques minéralurgiques commercialement rentables dans le cas des saumures renfermant des concentrations saturées de chlorure de sodium,d e potassium et de magnésium.

Diverses sociétés situées en Allemagne se sont spécialisées dans la conception et l'utilisation de l'extraction par solution ainsi que dans le traitement des saumures aux fins des marchés des engrais/produits chimiques à base de potassium et de magnésium. L'établissement d'installations dotées de systèmes d'évaporation/de cristallisation pour le traitement de la saumure de sylvinite/carnallite est considéré comme une technique minéralurgique éprouvée sur le plan commercial.O n a également recours à des techniques de lixiviation spécialisées appelées « lixiviation différentielle » pour extraire de façon sélective le magnésium ou le potassium et améliorer la viabilité commerciale du traitement des minerais de sylvinite/carnallite.

Même si l'extraction par solution est reconnue comme un procédé concurrentiel du point de vue coût avec les techniques d'extraction de minerai conventionnelles, la consommation d'énergie que nécessite le traitement des saumures au moyen d'évaporateurs/de cristalliseurs chauffés à la vapeur pourrait être considérée comme un facteur limitant la mise en valeur de la concession de Millstream. Les techniques minéralurgiques d'extraction par solvants, la précipitation des alcalis et l'emploi de turbines à gaz de recyclage conjuguées pourraient être considérés comme des solutions de mise en valeur de rechange économiques. Il est recommandé qu'on effectue une évaluation économique technique de ces procédés pour chiffrer la faisabilité de l'extraction par solution et du traitement des saumures dans le cas précis de la concession de Millstream.

SECTION 2.0 INTRODUCTION

2.1 Background

The geology and alternatives for mining of the Millstream sylvinite/carnallite/potash property located in New Brunswick has been described in a number of studies. Solution mining has been identified as a potential development concept consistent with the complexity of the ore body. However, characterization of the brine or target product markets has not been defined and is necessary for the definitive selection of process technologies. The subject study is based on a review of published literature and an initial identification of process technologies considered to be applicable for the commercial treatment of a brine containing sodium, potassium and magnesium.

Both magnesium and potassium are recognized as the primary products for commercial development of the deposit. It is possible that the cost of potassium chloride production from brine may not be competitive with conventional potash ore processing facilities. Also, the potential for contamination of the potassium chloride brine with magnesium chloride will limit the commercial viability of the project if magnesium recovery is not considered. Valuable by-products such as bromine and iodine may increase the revenue potential.

2.2 Project Objectives

2.2.1 The overall project objective is to identify a process technology or technologies which may be integrated with solution mining of the Millstream potassium/magnesium prospect.

2.2.2 The assessment of process technologies will be based on a typical brine composition of magnesium chloride, sodium chloride, potassium chloride and magnesium bromide. The unique compositional characteristics of the Millstream prospect brine are unknown at this time and may be subject to further characterization studies.

2.2.3 The assessment of process technologies may also include an integration of unit operations and/or pretreatment of the brine such that existing and/or under utilized processors may utilize concentrated potassium chloride brine from the Millstream property.

2.2.4 The assessment of process technologies may also be used for treatment of liquid or solid effluents from existing processors as a means to treat tailings for enhanced recovery.

2.2.5 The assessment of process technologies is not market specific and will include a review of alternatives for magnesium and potassium.

2.3 Project Work Scope

2.3.1 Conduct a detailed literature search of technical publications, patents and general information on commercial facilities.

2.3.2 Conduct a detailed review of process chemistry in order to identify alternative methods for separation of brine constituents such as potassium, magnesium, bromide and impurities (such as iron, clays, etc.)

2.3.3 Identify alternative processing concepts, prepare block diagrams for each process and review literature on process technology.

2.3.4 Conduct a review of alternative technologies based on the commercial viability of process, market options, impact on environment and relative cost.

2.3.5 Select three process alternatives that are considered technically and economically viable for further assessment.

2.3.6 Prepare a draft and final report of study results.

2.4 Conventional Processing of Ores

2.4.1 Potash from Sylvinite Ore Processing
(Reference Block Diagram 6525-BD-1000-001 of Appendix I)

The upgrading of sylvinite ores is generally done by flotation unit operations. Flotation is used to separate potassium chloride and sodium chloride after the removal of clays and fines by screens, cyclones, etc. Potassium chloride is subsequently dewatered, dried and screened to segregate product by particle size for market.

Crystallizers are not commonly used for the processing of sylvinite ores. However, to improve on potassium chloride recovery from brines or, if hot leaching is required to separate sodium chloride, crystallization is used to recover potassium chloride as a high purity product.

2.4.2 Potash from Carnallite Ore Processing
(Reference Block Diagram 6525-BD-1000-002 of Appendix I)

Bulk production of potash from carnallite ores has been commercially developed to separate potassium, magnesium and sodium chloride salts. The conventional process makes use of brine to dissolve the magnesium chloride while the subsequent separation of potassium chloride and sodium chloride is done by flotation. The magnesium chloride brine is treated by evaporation unit operations to recover flake grade magnesium chloride.

2.5 Solution Mining

Solution mining in Europe is considered a commercially viable technology for the development of sylvinite and carnallite ores. The technology has been used for more than fifteen years for the production of magnesium chloride at the Deusa plant located in Bieicherode, Germany. A detailed report on the plant operations was not available and is subject to further review.

Solution mining has a number of technological advantages over conventional mining methods and may be considered an economical and ecologically favourable method for the development of the Millstream property. In addition to the capital and operating cost advantages, solution mining will offer an increased yield for the deposit, improved quality of product (with high selectivity) and less risk associated with mine stability (such as subsidence, gas hazards, hydrological flooding of caverns and rock failures).

The technical viability of solution mining at the Millsteam property has not been defined and further studies will be required to assess the solution mining principles. The technical viability of solution mining will depend on the structural integrity, size and composition of the caverns. It will also depend on the quantification of leaching parameters such as rate of dissolution (relative to brine concentration and temperature), amount of solubles and in situ density.

Another important variable is the selection of process technology for the treatment of brine. To date, the nominal and variability of the brine chemical and physical characteristics have not been defined for the Millstream property. The actual brine concentration will depend on the location within the ore body and the economic criteria for the project. The degree of magnesium saturation within the brine is not known and will depend on the definitive location of wells within the ore body. Therefore, the subject review of process technologies is based on brine that may contain near saturation concentrations of sodium, potassium and magnesium.

2.6 Product Markets

The overall commercial viability of the Millstream property will depend on the target market, product value/revenue and the selection of the process/mining technology to comply with competitive production costs. The ore body consists of complex pockets of sylvinite and carnallite, therefore, the selection of the well location will also be dependent on the target market.

The ability to locate a well and maintain a brine quality that complies with the overall production and marketing plan is the primary consideration for the development of the Millstream property. It is not certain whether low

concentrations of magnesium can be achieved, as required for the processing of potash, based on the amount of brine characterization and the identification of well/cavern locations within the ore zone. Magnesium is defined by potash producers as an impurity that is costly to separate from potassium chloride. On the other hand, if the brine is saturated with magnesium, the production of potash is considered a co-product to magnesium production and the overall project economics will be based on multi-product markets.

Definitive marketing plans have not been developed for the Millstream project and will depend on the technological options for both solution mining and processing of brines. For the general review of process technologies, the market options have been identified as follows:

Potassium

Potassium chloride fertilizer grade
Potassium chloride of high purity

NOTE: Production of potassium hydroxide by electrochemical methods was not considered viable as a result of market location, high electricity costs and over production within the Northeastern United States.

Magnesium

Magnesium chloride flake grade
Magnesium hydroxide reagent grade
Magnesium oxide for refractories

NOTE: Magnesium metal was not considered as a result of the potential for over-supply and the cost of electricity within New Brunswick.

Iodine / Bromine Co-production

Bromine and bromine chemicals

Iodine and iodine chemicals

NOTE: Most brines contain both bromine and iodine. The Millstream property is known to contain bromine up to 3000 ppm. Iodine concentrations within the ore have not been determined. Commercial brine refining facilities have exploited the production of other alkali chlorides, which occur in low concentrations and have a significant revenue potential, such as lithium and rubidium (rubidium may be substituted for potassium in the carnallite crystal lattice). Further characterization of the ore body should include accountability for all alkali elements of economic significance.

SECTION 3.0 PROCESS TECHNOLOGIES - LITERATURE REVIEW

A literature review of process technologies was completed based on the concept of treating potassium and/or a magnesium rich brine, resulting from solution mining of the Millstream evaporite deposit. The review of process technology is not based on a specific composition of the brine and provides a general overview of unit operations designed to recover magnesium, potassium and other components that may add value to the project.

The review of process technologies is also based on commercially proven technologies that have been demonstrated to be technically viable by industrial applications or have been pilot tested. The review is intended to identify alternative technologies that may provide a direction for the commercial development of the Millstream evaporite deposit.

In addition to the treatment of brines produced from solution mining, technologies used to treat brines within sylvinite ore processing facilities are also considered. The treatment of brine processing technologies may reduce operating costs or add value to the existing sylvinite ore process operations within New Brunswick. The potential to integrate brine processing technologies with sylvinite ore processing unit operations has been recently identified in Europe as a viable commercial process (ie. use of solvent extraction processing technologies to reduce energy loads on crystallization unit operations).

3.1 Primary Treatment

The concentration or net loading of the insoluble solids, which may be typical for the Millstream brine, has not been defined. Most brines contain clay and silt which have an impact on brine separation efficiency and maintenance costs. Removal of insoluble solids to less than 25 mg/l is generally required. Chloride salts used in electrochemical production facilities require less than 5 mg/l insoluble solids. A detailed characterization of the insoluble solids is required to define target removal requirements.

In general, conventional solid/liquid separation equipment such as clarifiers and sand filters are used to recover insoluble solids prior to brine treatment. In some cases the use of flocculants and clarifiers are ineffective and pre-coat filters are employed. The use of back pulse candle filters improves pre-treatment costs.

Depending on the compositional characteristics and understanding of the ore body, the insoluble content of the brine may be unpredictable. A rapid increase in insoluble concentrations will have an impact on the plant efficiency and cost of operation. Generally a pre-sedimentation pond is used to equalize loading and reduce surge effects.

Insoluble solids are recovered and discharged with the waste streams without further treatment. Insoluble solids do not have an environmental impact, however, a full characterization of the insoluble content is required to confirm compliance with environmental regulation. Standard solid/ liquid separation units for removal of silt is commercially available and removal of solids less than 10 micron will not impact on the technical viability of Millstream brine treatment. However, if the loading of silt is high, the economic viability may be directly impacted.

3.2 Selective Dissolution - Hot and Cold Leaching

Selective leaching of magnesium and potassium is generally done by controlling the solute concentration and the solution temperature. Leaching unit operations are used in conventional sylvinite ore processing facilities for added recovery of potassium chloride from fines and leaching is also the primary separation unit operation in carnallite ore processing facilities. In the event that pre-evaporation (using solar ponds) is used to recover crude carnallite from brine, the harvested carnallite is treated with conventional leaching unit operations.

Hot leaching processing technology is commonly used to separate sodium chloride from potassium chloride. The process usually includes two stages of leaching with intermediate washing of the solids to remove residual salt. The potassium chloride is leached and the hot brine is saturated with potassium chloride so that the sodium chloride will stay in the solid phase. Flotation is generally used to separate solid phase sodium chloride and potassium chloride.

Cold leaching is often referred to by various processors as "cold crystallization". The leach is operated at ambient conditions and will reduce energy consumption. Cold water is added in agitated leach tanks to dissolve magnesium chloride and control solution concentration of potassium chloride so that the re-crystallization of potassium chloride occurs. The leaching is usually done in two to three stages with intermediate washing to maintain magnesium chloride in the solution phase.

3.3 Flotation

Flotation is commonly used to separate sodium chloride in solid phase from sylvinite and carnallite ores. Clay slimes may interfere with flotation and are generally removed by physical-mechanical desliming techniques prior to flotation. Most flotation circuits use alkyl morpholine as a collecting agent and operate at room temperature.

The use of flotation for the treatment of brines may be applicable to the crystallization of crude sylvinite or carnallite. Further upgrading using flotation to separate sodium chloride for K- fertilizer or Mg/K - fertilizer markets will result in lower energy costs. Flotation would be considered the lowest cost processing option for the treatment of crude precipitates if direct use in fertilizers is considered a viable market.

3.4 Evaporation/Crystallization of Brines
(Reference Block Diagram 6525-BD-2000-001 and 002 of Appendix II)

The use of evaporators and crystallizers for the treatment of magnesium/potassium brines has been identified as the best available technology and is commercially accepted by large scale industrial operations. Evaporators are generally used as the primary separation and crystallizers are used for production of high purity definitively shaped crystals, with consistent size and bulk density. The principles of operation for both evaporator and crystallizers are based on the solubility of alkali chlorides. A general description of the operating principles for both unit operations are summarized as follows:

Evaporation [1]

Evaporators are used to evaporate the volatile solvent and, in the case of brine treatment, water is the solvent. The operating objective is to concentrate the non-volatile solutes such as sodium chloride, potassium chloride and magnesium chloride. Evaporation of the solute results in the formation of crystals based on the solubility of the solute. Relative to the solubility of the alkali chloride in the brine, sodium chloride will crystallize prior to potassium chloride. A further decrease in the solute concentration by additional evaporation will result in the formation of potassium chloride crystals; resulting in a brine rich in magnesium chloride. The crystals are usually separated from the brine by cyclones, settling vessels, wash columns, filters and centrifuges. Filter washing of the crystals with the solvent is generally done to remove residual brine.

For sodium, potassium and magnesium brines, multiple effect forced circulation evaporators are commonly used. The brine solution is pumped through tubes within a shell that is heated with steam. The hot solution is pumped into a vessel which allows the vapors to rise and the solids settle to the bottom elutriation leg. A high recirculation rate of the solution is maintained to achieve optimum heat transfer and to minimize super-saturation of the stream.

Crystallization [1]

Crystallization is an industrial process for producing high purity compounds from impure solutions. The design of a crystallizer is based on its ability to promote crystal growth and the formation of large uniform particles. The phenomenon known as nucleation is caused by the contact of crystals with each other and the nucleation rate is the growth rate of the crystals; all controlled by the crystallizer when the solute is in a supersaturated solution.

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[1] For additional information on forced circulation evaporators and draft tube crystallizers, please refer to **Swenson Technology Inc.** on their web site www.swenson-equip.com.

The use of a draft tube baffle (DTB) crystallizer is preferred for potassium chloride where excess nucleation is required to achieve a crystal size of 10 to 30 mesh. The crystallizer includes a baffle section (containing an agitator for circulation/mixing) that suspends the slurry of the slow growing crystals and removes the mother liquor containing fines. The fines are destroyed by adding heat or by adding solvent. The overflow from the baffle zone allows the oversize crystals to settle to the bottom of the crystallizer.

The production technology for the separation of sodium, potassium and/or magnesium from brines using evaporation techniques is proprietary and may vary depending on the composition of the brine. Process technologies have evolved to improve on the selectivity of the separation by controlling solution concentrations and the reduction of heat load. A significant amount of research has been completed in Germany and in China on the principles of evaporation, preparation of detailed phase diagrams for K-Mg separation, and measures to control selectivity.

The selection of process technology for evaporation will also depend on the solution mining methods and provisions to control solution composition. A number of methods have been developed for the extraction of potassium rich strata and for the double salt (potassium and magnesium) rich strata. Recovery of magnesium chloride will require additional evaporation of water, which adds considerable energy costs for the treatment of brine. Alternative methods for control of brine composition (developed in Germany by Kutz) are based on the production of highly saturated double salt solutions. The less soluble salt (potassium chloride) precipitates as a slurry and is left in the bottom of the cavity. It is then removed as a slurry entrained by the saturated solution of the most soluble salt (magnesium chloride).

Competitive processing of brines using evaporator technology requires a good understanding of energy requirements for the evaporation of large quantities of water. For recovery of magnesium chloride, it is estimated that approximately 6 to 12 tonnes of water evaporation is required per tonne of magnesium oxide equivalent (conversion: 1 tonne of magnesium oxide = 2.4 tonnes of magnesium chloride). Based on the cost of fuel at about $2.77 per million Btu, the cost of energy for evaporation will range from $60 to $120 per tonne of magnesium oxide equivalent (based on the brine containing about 400 to 450 g/l of magnesium chloride).

This energy consumption is not based on optimum heat recovery methods and is considered the worst case for a process with low thermal efficiency. To improve on the operating costs related to thermal efficiency, commercial technologies for brine treatment have optimized on heat recovery and the design of evaporation process equipment. Some of the most recent technological developments, aimed at reducing evaporator energy costs are:

- ❑ development of the cold crystallization process that is based on the water leaching of magnesium chloride at low temperatures.

- ❑ development of new energy efficient crystallizers for potassium chloride product. US Filter has recently announced the installation of five new crystallizers at the Dead Sea Works Ltd. for the production of 1.3 million tonnes of potassium chloride.

- ❑ development of Thermal Vapor Compression (TVC) and Mechanical Vapor Re-compression (MCR) evaporators which are designed to reduce energy costs up to 50% by using multiple effect evaporators.

- ❑ use of heat recovery systems such as heating brine with an evaporator vapor condenser.

The production of potassium chloride from carnallite brines by crystallization is a proven commercially viable process in Germany. A detailed assessment of competitive processing costs, relative to conventional ore processing has not been defined in the literature. The process technology for the production of potassium fertilizers containing 60% K_2O is summarized as follows.

- ❑ the hot carnallite brine contains 300 to 350 mg/l of magnesium chloride, 50 to 60 mg/l potassium chloride and 20 to 25 mg/l of sodium chloride.

- ❑ initial treatment of the brine is based on cooling that separates crystals from the mother liquid of magnesium chloride. The potassium crystals are treated with a low concentration of magnesium chloride solution and recrystallized to form a purified solution of potassium

chloride, which is subsequently purified by a five-stage crystallizer.

- the potassium chloride crystals are stage washed in centrifuges and dewatered for fertilizer end use.

- the vapors from the evaporators are condensed and the hot condensate is used to heat the brine. The process generates about 60 tonnes of condensate for every 1000 cubic meters of carnallite brine treated.

Kali B Umwelttechnik GmbH (K-UTEC) of Germany has developed extensive expertise on solar evaporation technology for halite/carnallite fractional crystallization. Development and design of the process was based on treatment of natural brines for the National Iranian Potash Project; based on target production of 50,000 tonnes per year of potassium chloride fertilizer grade and 30,000 tonnes of magnesium hydroxide. The process has been pilot tested and modeled with a synthetic brine. The data has been compared to a commercial operating system to evaluate, design and verify process parameters for solar evaporation systems. In summary, the technology has the following operating/design features that correspond to the commercial operation of solar evaporation:

- brine feed to the solar evaporation system is saturated with sodium chloride, which is achieved by brine recirculation to the ore. Sodium chloride crystallizes immediately in the first and second ponds.

- potassium chloride is concentrated to about 21 kg/m^3. Above a brine density of 1.38 g/cc the crystallization of carnallite begins and the potassium chloride concentration is lowered to 5 kg/m^3. The potash yield is about 78% from the solar pond.

- crystallization of carnallite occurs so that the solids contain about 25% halite and about 75% carnallite.

- the solar ponds are designed so that a majority of the halite is crystallized in the first two pond and carnallite is crystallized in the fourth and fifth pond. The carnallite is harvested from the ponds and potash is refined by flotation.

Solar evaporation technologies are also commonly used in China and four alternative methods for solar evaporation have been identified by the Qinghai Potash Fertilizer Project. Since 1999, these technologies have been under review for the treatment of carnallite brine at the Chaerhan Salt lake. Studies have been completed, which compare alternative solar technologies, and are published in Chinese (translation unavailable). Based on studies conducted by the Chinese on the refining of carnallite brine from the Qinghai Salt Lake, the variation in the brine temperature has a direct influence on the separation of potassium chloride from the carnallite brines.

Development of a highly energy efficient process technology by Vulkan B verlag GmbH is under assessment for the treatment of solution mining carnallite ores of Bleicherode, Germany. Innovative methods were studied in 1999 and commercial implementation of gas turbine/steam heating of the brine is unknown. The technology is based on a selective hot extraction. Both thermal energy and electricity are supplied by a combined cycle natural gas fired turbine. Publications are in German and information on the energy saving will require further review.

A significant amount of evaporation/crystallization technology has been developed by VEB Kombinat Kali of Germany for the production of both magnesium and potassium products. Various patents have been filed in German (translation unavailable) and are based on methods to reduce energy costs and to improve magnesium chloride purity at high yields. From 1984 to 1992, the firm has developed fully integrated technologies for solution mining and primary treatment of brine. A detailed review of the technologies was not completed and is also subject to further review. A summary of the technologies developed are as follows:

- washing and crystallization technologies for the separation of sodium chloride from potassium chloride and production of high purity potassium chloride using filtration and crystallization unit operations.

❑ development of methods to increase the concentration of potassium chloride in the brine using multistage cold brine treatment methods. Brines have been concentrated to achieve 331 mg/l of magnesium chloride and 65 mg/l potassium chloride. The process was developed for the production of potassium fertilizers from carnallite brine operations.

❑ development of process methods for the removal of sulfate from magnesium chloride brines using partial evaporation and cooling of hot brines.

❑ development of vacuum crystallization for the production of a crude carnallite and separation from sodium chloride. The production of the crude carnallite is used for fertilizer and co-production of a sodium chloride sludge.

❑ development of a fully integrated process for the separation of magnesium chloride/ potassium chloride and sodium chloride from carnallite brine using crystallization and hot leaching techniques. The process also includes the removal of bromine from the magnesium chloride brine for high purity magnesium chloride end users.

❑ development of sodium chloride brine systems to improve on the leaching of carnallite and selectivity of the leaching process.

❑ development of process technology for the production of potassium sulfate from potassium chloride and magnesium sulfate. The co-production of magnesium chloride brine of high purity can be used for speciality added value applications.

3.4.1 Alkali Precipitation

(Reference Block Diagram 6525-BD-2000-003 and 004 of Appendix II)

Alkali precipitation is the most common method for treating seawater brine. The brine is treated to precipitate both calcium and magnesium as an hydroxide or carbonate using an alkali hydroxide or alkali carbonate to increase the pH to about 10.5. The resulting brine preferably contains sodium chloride and potassium chloride. Although this technology is commercially used for electrochemical cell operations, the use of this technology for treatment of carnallite brine will require further assessment. Use of low grade dolomite or limestone as an integral part of brine treatment is considered technically viable and assessment of process economics will require further review.

Magnesium hydroxide is also commercially recovered by the reaction of calcium oxide and magnesium chloride. This process is commonly used for the treatment and recovery of magnesium from sea water. About 1.4 tonnes of calcium oxide is required for each tonne of magnesium oxide produced. Magnesium hydroxide is insoluble and is separated from the calcium chloride under controlled conditions. The solid/liquid separation requires significant capital expenditures, which may limit its commercial viability. Extensive pilot tests have been completed by NEDMAG Industries in Holland to optimize magnesium hydroxide production from the addition of lime to magnesium chloride brines containing 32% by weight. It is understood that pilot programs for commercial design of a production facility are presently in progress.

A novel process has been developed for exploitation of carnallite ores of Brazil for the recovery of potassium and magnesium. The process is based on the addition of ammonia to carnallite brine and precipitation of magnesium hydroxide. The residual brine, containing ammonia, potassium and magnesium, is subsequently precipitated using a selective solvent mixture of acetone and isopropanol. The precipitated magnesium hydroxide is washed and dewatered using a centrifuge. Details of the solvent recovery and overall process economics were not published. It is also known that selective crystallization is being investigated as an option to solvent precipitation.

3.4.2 Solvent Extraction

(Reference Block Diagram 6525-BD-2000-005 of Appendix II)

Solvent extraction technologies have been commercially developed for the purification of brines and/ or removal of soluble impurities. The principles of solvent extraction are based on the use of an organic that may have a selective dissolution of a chloride salt or may complex with the alkali elements to form an alkali-organic complex.

The use of organic chemicals for selective precipitation of magnesium chloride is a known technology for the purification of magnesium chloride rich brines. The commercial application of the technology has not been reported in the literature and the economics of a high tonnage operation are not known. The subject technology is considered if trace concentrations of potassium in magnesium chloride brine are specified as an end use application. A summary of organic solvent used for selective precipitation is as follows:

- ❑ methanol added to a concentrated potassium chloride brine with up to 6% by weight magnesium chloride will enable precipitation of potassium chloride of high purity. This technology may also be used on carnallite brines, which is capable of producing potassium chloride of about 92% grade. The recovery of methanol has economic significance and is usually done by evaporation and is subsequently condensed and distilled for reuse.

- ❑ anhydrous ethylene glycol is used for the production of anhydrous magnesium chloride (used for the production of metal by molten salt electrolysis). The glycol/magnesium chloride solution is treated with ammonia to form insoluble magnesium chloride ammoniate salt. Subsequent washing and roasting is used to drive ammonia off in the gas phase and form an anhydrous magnesium chloride. The ethylene glycol is recovered and recycled. The technology is considered technically viable for the treatment of carnallite brine. Further review is required to determine the economic viability of this technology.

- use of dioxane (1,4-dioxane or 1,3-dioxane) was found to be highly selective for the treatment of carnallite brines. Magnesium chloride is precipitated in a solution of dioxane; as a complex of magnesium chloride dihydrate. About 10 to 25% by volume of dioxane is required to achieve a high selectivity and recovery at room temperature. The magnesium chloride precipitate is recovered and washed by filtration unit operations. Dioxane in the precipitate is recovered by condensation of the drier off gas and the drying temperature will also be used to control the degree of hydration of the magnesium chloride. A majority of the dioxane is recovered from the filtrate by distillation with recoveries around 96%.

Solvent extraction circuits, which employ complexing organic chemicals in counter current mixer/settlers, are not commonly used for the refining of magnesium or potassium chlorides. Commercial circuits have been installed in the United States and Russia for optimum purification of concentrated brines. Recent developments in the use of multi-stage column solvent extraction technology have spurred interest in the use of solvent extraction as primary brine separation unit operations. In most cases, the application of solvent extraction is summarized as follows.

Di-2-ethylhexyl Phosphoric Acid (D_2EHPA)

A solvent extraction process was installed for the purification of magnesium chloride solutions at the Slovak Magnesite Works in Czechoslovakia. The plant, which had an annual capacity of 26,000 tonnes of magnesium oxide, employed D_2EHPA to remove impurities (predominately calcium chloride) from the brine prior to spray roaster operations to produce magnesium oxide. The plant was capable of producing magnesium oxide at 99.5% purity with less than 0.05% calcium oxide. Before closure of the plant, pilot studies were conducted using a D_2EHPA solvent extraction circuit to produce magnesium oxide greater than 99.9% grade using ammonium carbonate pressure precipitation. Details of the technology are not available for review.

Tri-butyl Phosphate (TBP)

The technical viability of using TBP solvent extraction for purification of magnesium chloride is limited by acid concentrations. In most cases a high concentration of acid is required to maintain a high degree of selectivity for the separation of alkali chlorides. Therefore, the use of TBP in brine treatment is not considered viable for primary separation of sodium/magnesium/potassium brines.

Although the removal of iron chloride complexes from brine has not been addressed by published literature, TBP may be used for the removal of trace iron from brine solution. The concentration of iron in the Millstream brine is not known therefore removal of iron using TBP will require further review.

Magnesium oxide production for refractory end use has definitive product quality specifications with respect to lithium and boron content. Although the boron content in the Millstream deposit is unknown, the removal of boron from magnesium chloride brine can be achieved by solvent extraction. Commercial methods for the treatment of brine from the Chaidam Basin within China are based on the acidification of the brine and the use of tributyl-phosphate solvent extraction. These unit operations are used as final stages of brine treatment.

Mixed Reagents (Alamine 336 and Versatic 10)

Development of solvent extraction using a mixture of reagents was completed by Dow Chemicals around 1960. The extraction of magnesium from sea water was based on a mixture of quaternary amine (Alamine 336) and carboxylic acid (Versatic 10). It is not certain if the process was technically viable and if the technology can be used for treatment of brine based on the studies completed by Dow.

As a follow-up to the preliminary work completed by Dow, Novadel of England has developed a solvent extraction process that is capable of producing a high purity magnesium chloride. Further review of this technology is required to assess the application to brine treatment.

The Department of Mining and Mineral Engineering at the University of Leeds has recently developed mixed reagent solvent extraction circuits for brine treatment. The process is capable of separating magnesium, sodium and potassium. Commercial advantages of the process technology are defined as follows:

- ❑ low consumption of energy; relative to the operation of staged crystallization.
- ❑ regeneration of the reagent is technically viable at room temperature without the need for high temperature distillation. The technology provides a cost effective method for the reuse of organic reagents.
- ❑ the process is highly selective and capable of producing a highly concentrated magnesium and potassium chloride brine.

3.5 Bromine Recovery

(Reference Block Diagram 6525-BD-3000-001 of Appendix III)

Most commercial bromine producing plants require a source of bromine that contains greater than 1.0 g/L Br in order to make the process of recovering bromine from bromide-rich brines economically viable. The process is also commonly used in the mining industry as a means of removing bromine and iodine from end products such as potash, carnallite, and various other mineral salts which, in accordance with government and end user product quality specifications, may contain only small concentrations of these impurities.

The commercially proven process for recovery of bromine from bromide-containing brines is generally referred to as the "steaming-out process". In this process, the bromide-containing brine flows downward through a

packed tower or contact column containing raschig rings. At the same time, low pressure steam and a slight excess of the theoretical amount of chlorine required are introduced just above the bottom of the tower. The chlorine, which has a higher reduction potential than bromine, oxidizes the bromide to bromine.

Bromine is liberated from the brine in the form of a vapour, which is subsequently condensed in a tantalum condenser along with steam and chlorine gas. The condensed liquid mixture may then be separated using a gravity and/or phase separator that operates on the principal of differential density of the liquids in the mixture. Bromine, with an average density of 3.1 tonne/m^3, is much heavier than water, which has a density at room temperature of 1.0 tonne/m^3, and will settle to the bottom of the gravity separation chamber. The dense phase, liquid bromine, is then continuously drawn from the bottom of the gravity separator and fed to the purification step where any residual chlorine and water will be removed via distillation. The light phase, which is water, will be returned to the stripping tower.

The steaming out process is a commercially proven and technically viable method for removing trace concentrations of bromine from mineral salt brines, which is what would result from the solution mining of sylvinite and/or carnallite from the Millstream prospect. There are also many ways to improve on the efficiency of this process in order to make the overall economics of the potassium or magnesium plant more favourable.

3.6 Iodine Recovery

The process of iodine recovery is very similar to that of bromine recovery. Iodine, whose reduction potential is lower than that of chlorine, is oxidized by the introduction of chlorine gas to the feed brine in a vertical contacting reaction column. As was the case for bromine, steam may be used to strip the iodine from the brine. In order to make the steaming-out process for iodine and bromine recovery economically viable for the purpose of removing low concentration impurities from mineral salt solutions, the two halogens should be removed simultaneously.

The density and boiling point of iodine is significantly greater than that of bromine. Because of these differences in the physical properties of bromine and iodine, the two may be separated from water using a gravity settling chamber or phase separator. The two halogens may then be purified using the method of distillation, which utilizes the differences in boiling points to separate and remove any trace impurities from the two elements.

3.7 Magnesium Chloride Added Value Treatment

Dehydration of Carnallite / Magnesium Chloride

The removal of chemically bound water from carnallite or magnesium chloride crystals is achieved by the high temperature (200 to 230°C) dehydration of the solids. The reaction occurs in a rotary kiln or a fluidized bed reactor in the presence of hydrochloric acid. Chlorine gas may be added to a secondary chlorination reactor to prevent magnesium oxide formation and to assure conversion of the water to hydrochloric acid.

The dehydration of carnallite is commonly used for molten bath electrolysis, which requires super-hydrated feedstock. Natural gas is used for dehydration and the unit operation is considered a high energy consumer. Recent developments in fluidized bed technologies are noted to improve on efficiency of the conversion (minimized magnesium oxide content) and removal of moisture to greater than 98%.

Pyro-hydrolysis of Magnesium Chloride

The conversion of magnesium chloride in a concentrated brine solution can be performed using a high temperature spray roasting process. At about 600 to 800°C magnesium chloride is converted to magnesium oxide and hydrochloric acid using natural gas. The technology was developed by Andritz Rutherner of Germany and commercialized for the Dead Sea operations in the early seventies.

The products of pyro-hydrolysis include magnesium oxide powder and hydrochloric acid. In most cases, the acid may be sold or used to treat magnesium feedstocks (such as asbestos tailings, dolomite or magnesites) for intermediate production of magnesium chloride. The technology is also commonly used for the treatment of steel pickle liquors and is commercially proven.

Magnesium Metal

Production of magnesium metal is not considered a viable development option for the Millstream project because of market capacity and the number of projects that are expected to come on stream for metal production. Carnallite ore is commonly used as feedstock for the production of metal using the electrolytic or the thermal reduction processing routes.

It is possible that the excess or primary production of magnesium chloride may be used as a feedstock for a magnesium metal plant. Thus, magnesium chloride may be produced and sold in flake or solution form for metal production. The quality and chemical form of magnesium chloride (anhydrous versus heptahydrate) will depend on the end user technology and specifications.

The various operative processes for the electrolytic production of metal are Dow Process, Norsk Hydro Process, National Lead Industry Brine Process, American Magnesium Brine Process, USSR Process and MPLC Process. Thermo reduction processing includes the carbothermic reduction (which is not found to be commercially viable), the silico-thermic reduction process, namely the Pidgeon Process and the Magnetherm Process. World capacity of metal production is about 72% by electrolysis process and the balance through silico-thermal reduction.

Various studies have been completed on the production of magnesium metal from various magnesium sources located in New Brunswick. The development of Millstream carnallite for magnesium metal production was not considered viable because of high energy costs. Energy requirements for the production of metal may range from 30 to 40 KWh per kilogram of metal using electrolytic processing technology.

3.8 Potassium Chloride Added Value Treatment

Potassium Sulfate

Commercial processing technologies have been developed and are in operation for the production of potassium sulfate from potassium chloride brine. The source of sulfate may vary for each application and the most common brines with high sulfate concentrations are treated to recover sulfate as magnesium sulfate. This is subsequently reacted with potassium chloride to produce potassium sulfate. Production of potassium sulfate from brine solutions has been developed for the following projects.

Salt Lake, North Africa: Details on the technology have not been published however, the technology was developed in 1985 by Neue Bergbautechnik of Germany. The brine is concentrated by solar evaporation to produce a crude carnallite and sodium chloride. The carnallite brine is reacted with magnesium sulfate to produce magnesium chloride and potassium sulfate. Purity of the product, status of the operation and target markets/ quality specifications have not been reported.

The Big Quill Lake Project, Saskatchewan, Canada: The process was developed around 1987 and was based on the exchange of lake brine sulfate ions with potassium chloride brine. Details on the commercial viability of the process and definitive details of the process technology are not reported in the literature.

Production of potassium sulfate from potassium chloride brines is considered technically viable. Various technologies have been recently developed to produce potassium sulfate fertilizer grade, however, a detailed review has not been included with the subject study. The most recent developments have been reported by Airborne Industrial Minerals Inc. of Canada, Chemie Technik of Germany, and Tianjin College Light Industry of China. Each advancement which involves the treatment of potassium chloride brines using an alkali sulfate for the precipitation of potassium sulfate.

Potassium Nitrate

Potassium nitrate is commercially produced by the reaction of potassium chloride brine with nitric acid in an aqueous medium. Crystals of potassium nitrate precipitate are recovered leaving the resulting brine concentrated with hydrochloric acid. Hydrochloric acid may be separated and recovered by solvent extraction technology. The process also produces hydrochloric acid and sodium nitrate.

SECTION 4.0 COMMERCIAL BRINE RECOVERY FACILITIES

The selection of process technologies for specific ore bodies depend on the nature of the ore, the level of impurities and the target markets for primary and secondary products. Since a definitive brine composition and target market have not been developed for the Millstream project, definitive processing technologies have not been identified as project specific. A review of commercial operations has been completed to identify alternative processing technologies used to treat sodium, potassium and magnesium brines.

4.1 Dead Sea Works Ltd. (DSW)

DSW operates a fully integrated processing facility for the production of flake grade magnesium chloride, potassium chloride, granular salt, caustic, chorine and bromine products from the Dead Sea brine. Solar evaporation is used to precipitate salt, which is deficient in sulfates relative to sea water.

Carnallite is harvested from the solar ponds and is pumped as a slurry to the processing facility. The slurry is then leached in a counter-current system, which selectively dissolves the carnallite so that the potassium chloride will crystallize out of the solution. A "cold crystallization" and a "hot leaching process" is used to extract potassium. Soluble potassium is recovered by crystallization while magnesium chloride is recovered from the brine using evaporators. Bromine is recovered from the brine using chlorination and stream stripping, which is subsequently purified and used to produce bromine products.

The DSW processing technology is considered to be the conventional treatment for carnallite brines and is based on the selective dissolution and evaporation of brine. The production of potassium chloride is targeted for high purity/non-agricultural use of potassium and what is the world's largest producer of flake magnesium chloride. With high sodium chloride concentrations in the brine (as a result of non-selective solar evaporation), flotation has been used for several years to separate the fine potassium chloride from sodium chloride. It is also noted that conventional electrochemical unit operations (chlor-alkali technology) are used to produce chlorine and caustic. With improvements in solar evaporation and recent developments in the refinery technology, annual production capacity is about 2.2 million tonnes of potassium chloride and about 100,000 tonnes of

magnesium chloride.

The high capacity production of value added products and the use of a relatively low energy consumption process have contributed to the commercial viability of the production facility. Recent installation of low energy crystallization equipment will improve on the production costs for potassium chloride. It is believed that the use of the cold crystallization process reduces the energy consumption that is required for magnesium/potassium separation by multi-stage evaporators. This technology may prove to be a viable concept for the treatment of crude carnallite, integrated with solution mining operations.

4.2 Arab Potash Co. (APC)

APC also operates a processing facility limited to the production of potassium chloride fertilizer grade from the brine of the Dead Sea, located on the Jordanian. Solar evaporation is used to recover carnallite through a series of dyked areas. It is understood that the process technology is similar to DSW and has recently introduced the use of the "cold crystallization process".

The process technology is based on the separation of potassium and magnesium by re-crystallization, which requires less than 5% by weight sodium chloride in the feed. The use of the cold crystallization process has resulted in about a 15 to 20% reduction in energy consumption.

A majority of the developments in process technology at APC have focused on solar evaporation in an effort to increase production. As of 1996, annual production was planned for 2.35 million tonnes of potassium from harvested carnallite.

To improve on the overall economics of the production facility, APC has focused on the development of process systems for diversification into potassium hydroxide, potassium carbonate and high purity potassium chloride for medical and industrial use. Commercialization of these process systems is unknown and will require further review.

Extensive pilot tests and development of process systems for the production of magnesium oxide were considered for commercial start-up in 1998. Details of the process technology and economic viability have not been published and are subject to further review.

4.3 Dead Sea Magnesium Ltd. (DSM) - Israel

DSM, a primary producer of magnesium and magnesium alloys, is located on the south shores of the Dead Sea. The company is owned and operated by Israel Chemicals Ltd., and Volkswagen AG. The magnesium metal plant was constructed in 1995 and production is about 28,000 tonnes of metal annually. The refinery was also designed to produce fertilizer grade potassium chloride and bromine.

The production of magnesium from the electrolytic decomposition of carnallite is based on technology developed in Russia. Similar to other Dead Sea operations, the brine is evaporated using solar evaporation. Wet carnallite is recovered from solar ponds and fed directly to fluidized bed reactors for the dehydration of carnallite. It is noted that the development of the fluidized bed technology was based on the optimum production of anhydrous carnallite and the decomposition to magnesium oxide being controlled. The anhydrous carnallite is treated by electrolysis to form magnesium metal and the spent electrolyte containing potassium chloride is crystallized for fertilizer markets.

The process technology is considered similar to the proposed technology for the Kouilou Project of Africa. Electricity, being the critical component of the production, is generally supplied by the use of low cost hydro-electric power suppliers. In the case of the Dead Sea project, a co-generation plant was constructed for the production of 110 Megawatts to maintain a competitive position.

4.4 IMC Kalium Ogden Corp. - Great Salt Lake, Utah

A fully integrated production facility was developed by IMC for the production of sodium chloride, magnesium chloride, potassium sulfate and sodium sulfate from the brine of the Great Salt Lake. The location within a dry climate has contributed to the commercial viability of solar evaporation. IMC is capable of evaporation rates of about 100,000 gallons per minute over approximately 40,000 acres of ponds.

The primary separation of sodium chloride, potassium chloride and magnesium chloride is achieved by solar evaporation and the use of solar pond harvesting. The cascading flow of brine through the pond system is designed to allow for most of the sodium chloride precipitation in the first pond and subsequent potassium chloride precipitation. The magnesium chloride brine solution from the pond systems is marketed as a dusting agent and a portion of the brine is treated by evaporators for the recovery of flake magnesium chloride.

Sodium chloride is harvested, washed and dried with limited contamination. Most of the salt is returned to the lake and about 70,000 tonnes are treated for bulk and packaged markets.

Sodium sulfate also precipitates prior to potassium/magnesium mixed salt precipitation. Sodium sulfate is upgraded by leaching and subsequent drying to produce anyhydrous sodium sulfate.

Potassium precipitates in the pond as chlorides and sulfates. The Great Salt Lake brine is known to be high in sulfates. Potassium is recovered as a sulfate using a leaching technology to remove chlorides. Flotation is used to remove sodium chloride while crystallizers are used for the final purification prior to drying and screening operations.

The major difference in the Great Salt Lake brine processing, relative to common carnallite brine treatment systems, is the high concentration of sulfate. The processing of both sodium and potassium sulfate is based on the removal and washing of magnesium/sodium chloride from the sulfate products. Therefore, the process technology is not related to the treatment of carnallite brines for the recovery/separation of potassium and magnesium chlorides.

> **NOTE:** Other commercial operations that extract alkali elements from the Great Salt Lake include Magnesium Corporation of America, Cargill Salt, Morton International and North Shore Limited Partnership. A detailed review of the process technologies for each of these operators has not been completed.

4.5 Potash Company of Saskatchewan Inc.

PCA has used solution mining for the extraction of potash from Saskatoon mining operations. The mine has negligible concentrations of carnallite and the brine is pumped to a pond for recovery of potassium chloride crystals.

4.6 IMC Global Inc. - Saskatchewan / Michigan

IMC Global Inc. produces various potash products from potash mines in Canada and the United States. Solution mining technology is used at the Belle Plaine mine (located in Saskatchewan) and the Hersey mine (located in Michigan).

The process technology is based on solution mining of potash rich ores. Heated water is pumped within the ore zone, recovering the potassium and sodium chloride brine. The brine is refined by the use of evaporation and crystallization unit operations. A cooling pond is also used for crystallization of potash, which is harvested and refined for fertilizer markets.

4.7 Sergipe and Amazonas Deposits - Brazil

The development of the carnallite deposits of Brazil has been under review for several years and a novel processing concept has been defined. The process being developed is based on the use of ammoniation of the carnallite brine to produce ammonia/potassium/magnesium fertilizers and magnesium hydroxide. The economic viability of this process, based on the consumption of ammonia, would require further review.

4.8 Qinghai Salt Lake - China

Specific details on brine recovery operations have not been published. Development measures to improve on solar evaporation have been noted and further review is required to assess process technologies.

4.9 Magnesium Alloy Corporation - Kouilou Project

The Kouilou project is presently in the development phase (production is proposed for late 2005) and is based on the use of solution mining for the extraction of carnallite ore. The project is expected to produce approximately 60,000 tonnes per year of magnesium metal and co-produce potash and chlorine.

The process technology is based on the production of a carnallite dehydrate and the use of magnesium electrolytic cell technology developed by the Russian National Aluminum Magnesium Institute (VAMI). The primary brine treatment will include evaporation and crystallization to form high purity carnallite crystals. Fluidized bed systems will be used to thermally dehydrate carnallite to form potassium/magnesium chloride. The potassium chloride brine from the electrolysis cell will be treated by evaporation/crystallization to produce potassium chloride for fertilizer markets. Chlorine from the fluidized bed and electrolysis unit operations will be recovered as a gas for market.

The process technology is based on the use of natural gas and electricity purchased at $0.0175 per kilowatt. Electricity was estimated to be about 35% of the production cost and the project feasibility is based on an internal rate of return (IRR) of over 20%. Details on the process technology and the ability to produce a high quality magnesium metal are not reported in the literature and are subject to further review. It is worth noting that the design of solution mining and treatment of the brine by crystallization was completed by a German firm, Kavernen Bau-und Betriebs GmbH (KBB).

4.10 NEDMAG Industries - Netherlands

Definitive development of the Veendam carnallite mine has not been published by NEDMAG Industries. Solution mining is being used to extract magnesium but details on potassium production are limited. The mine is believed to have been developed for the production of magnesium oxide for the refractory markets. The brine, which is treated with lime to precipitate magnesium hydroxide, is also subjected to thermal hydrolysis for the production of magnesium oxide and hydrochloric acid. Over the last few years, Nedmag has been testing a novel process for thermal hydrolysis using fluidized bed reactors to produce a unique magnesium oxide product.

4.11 Cleveland Potash Ltd. - England

The Cleveland Potash Boulby mine started production around 1973. It is not a typical brine treatment operation but instead utilizes a unique technology for treatment of the brine. An increase in the clay content of the ore has resulted in the need to wash the clay and recover the brine in order to reduce loss of potassium chloride with the clay. Further review is required to assess the brine treatment process, however, it is noted that the increase in brine volume has increased the consumption of energy.

As a measure to reduce operating costs of the brine treatment circuit, solvent extraction process technology was developed. The process technology is based on the use of D_2EHPA to selectively remove both calcium and magnesium from the potassium chloride brine. A secondary stage of solvent extraction uses Aliquat 336 - Versatic 10 to separate sodium chloride and potassium chloride. Preliminary studies have indicated that solvent extraction circuits may replace the conventional crystallization circuits, however, details of the process economics have not been published.

4.12 Dow Chemical Co - Michigan, United States

Dow has developed a commercial process for the treatment of magnesium chloride brines from wells for the production of magnesium chemicals. In addition to Dow, both Martin Marietta Chemicals and Morton Chemicals Co., have developed commercial operations for the treatment of well brines in Michigan, United States. Further review would be required to defined process technolgies specific to these operations.

The process technology developed by Dow for the Midland Brine Chemical operation is based on alkali precipitation. A local source of calcium carbonate or dolomite is used to control the pH of the brine and precipitate magnesium as magnesium hydroxide. The magnesium hydroxide is used for the production of magnesium oxide and magnesium sulfate.

The addition of lime or dolomite will result in the co-production of calcium chloride. Calcium chloride brine is concentrated by evaporation and crystallized as calcium chloride flake.

Prior to the treatment of well brine for magnesium recovery, bromine is extracted using chlorination and steam stripping. A fully integrated bromine chemical production facility is capable of producing sodium/potassium bromide, bromine chloride, calcium bromide, zinc bromide, ammonium bromide and hydrogen bromide.

Brine from the prodution wells is not typical of carnallite brine but the treatment concept has commercial potential for solution mining applications. Although the technology results in the treatment of an additional salt (calcium chloride), both the additional revenue and the use of a low cost reagent as opposed to evaporation may improve on the commercial viability of carnallite brine treatment.

4.13 Solikamsk Magnesium Works (SMW) - Russia

The SMW Russian smelter, which started production in 1936, has been the primary magnesium metal producer for many years. The process technology used to treat carnallite from the Verkhnekamskoye deposit was developed by SMW and provides the foundation for technologies used by the Dead Sea magnesium and the Kouilou project.

The process technology is based on the dehydration, chlorination and electrolytic production of magnesium metal from carnallite. The method for the purification of the carnallite has not been published and it is possible that impurities are so low that purification unit operations are not required.

4.14 Carnallite Brines from Carnallite Ores

Carnallite deposits are commonly mined for the production of potassium chloride fertilizer grade and magnesium chloride brine. The separation of the alkali chloride is achieved by dissolution of the ore to produce a potassium/magnesium rich brine. Processing of the brine is similar to the treatment of brines resulting from solution mining and/or harvesting of crude carnallite from evaporation ponds. In summary, processing of the carnallite ores has been commercially developed at the following mines and the process technology may be applicable to solution mining operations:

Potassas de Navarra SA - Spain

The carnallite ores are primarily composed of carnallite and halite with no sulfates of magnesium and potassium. The ore is leached with cold water to selectively remove magnesium and an evaporation circuit is used to concentrate a magnesium rich brine. The residue is then leached with hot water to dissolve potassium chloride resulting in sodium chloride waste. Potassium chloride is crystallized and dried as a finished product.

Hattorf and Wintershall Mines - Germany

The ore is ground and leached in a solution at 90°C to decompose the carnallite and produce a non-saturated solution of potassium chloride. The brine is cooled to about 30°C in vacuum coolers whereby potassium chloride precipitates. The precipitate is leached with cold water to remove sodium chloride.

Salzdefurth Mine - Germany

The ore is leached with cold water at 25°C to form a brine containing about 300 g/l magnesium chloride. Solids from the cold leach are treated with a hot leach and potassium chloride is recovered by crystallization.

Werra Combine - Germany

The process is similar to the technology used at the Hattorf and Winetrshall mines.

Teutschenthal Mines - Germany

The ore is leached at 100°C to dissolve both magnesium and potassium so that the solution is saturated with potassium chloride. The solution is cooled to precipitate potassium and sodium chloride. To reduce loss, a second stage evaporator is used to concentrate the magnesium chloride to about 240 g/l.

SECTION 5.0 CONCLUSIONS AND RECOMMENDATIONS

The initial review of process technologies used to treat sylvinite and carnallite brines has identified that it is technically viable to separate sodium, potassium and magnesium chlorides, and subsequently produce high quality marketable products. Commercially viable process technologies are based on controlling the solubility of sodium, potassium and magnesium in an aqueous solution. Either aqueous evaporation (used to precipitate an alkali chloride) or aqueous leaching (used to dissolve an alkali chloride) can be used to selectively separate sodium, potassium and magnesium.

The commercial development of a brine processing facility for the Millstream property would include a selection of evaporation and leaching unit operations. Definitive design of a process technology will depend on the relative ratio and the concentration of all alkali chlorides, which will also depend on solution mining methods and the location of wells. Further studies are required to determine alkali solubility characteristics relative to the selection of process unit operations.

The assessment of brine processing technologies has identified alternative unit operations which may reduce energy consumption and improve on the commercial viability of Millstream development. These technologies were not identified as conventional processing methods for sylvinite and/or carnallite brine but are commercially used for brine processing. In general, the process technologies that may be integrated with solution mining of the Millstream property include the following:

Hot Brine / Surface Cooling

Hot brine may be used to optimize on solubility and dissolution of the alkali chlorides. Options to enhance selectivity of dissolution within the well should also be considered. Surface cooling of brine will enable crystallization of the crude salt. Further processing of the salt may include conventional unit operations, as required for processing of sylvinite or carnallite type ores.

Alkali Precipitation

Use of dolomite or lime for precipitation of magnesium from the potassium chloride brine and subsequent treatment of the brine by evaporation/crystallization unit operations.

Solvent Extraction

Although solvent extraction using D_2EHPA, Alamine 336, and Versatic 10 has not been commercially used for brines, the process technology has a number of commercial advantages. The benefits, mainly low consumption of energy, would support the development of the process for sylvinite/carnallite brine treatment. Also, integration of solvent extraction technology with hot brine surface cooling or alkali precipitation may improve on process economics.

The relative economic viability of the project should be based on revenue from all products, solution mining costs, as well as brine processing costs. The cost of solution mining may be lower relative to ore extraction and grinding costs, but the advantages may be off-set by the energy costs associated with brine processing. Energy costs for the proposed Millstream process options may be higher than conventional ore processing by flotation, but lower than multi-stage evaporation using in-plant heater/evaporators. Specific unit operations, which may be integrated with the proposed processing technologies to improve on operating costs, are defined as:

- ❒ use of gas turbines used to produce electricity and low pressure steam. It is possible that units in the range of 75 to 110 MW may improve on overall economical viability.

- ❒ use of vacuum or mechanical compression evaporators, to reduce energy costs up to 50%.

- ❒ use of vapor condensers on evaporator systems to pre-heat brine, optimizing heat recovery.

The development of the Millstream property may be commercially viable, based on solution mining and the application of brine treatment technologies as defined herein. The project's feasibility will depend on process technology, energy costs and product marketing factors that are ore specific. It is recommended that an additional study be undertaken to further assess project feasibility, to include the following tasks.

A) Identification of appropriate solution mining models for Millstream and resultant brine composition.

B) Identification of process technologies based on specific brine compositions.

C) Development of a preliminary conceptual design and capital/operating cost estimate.

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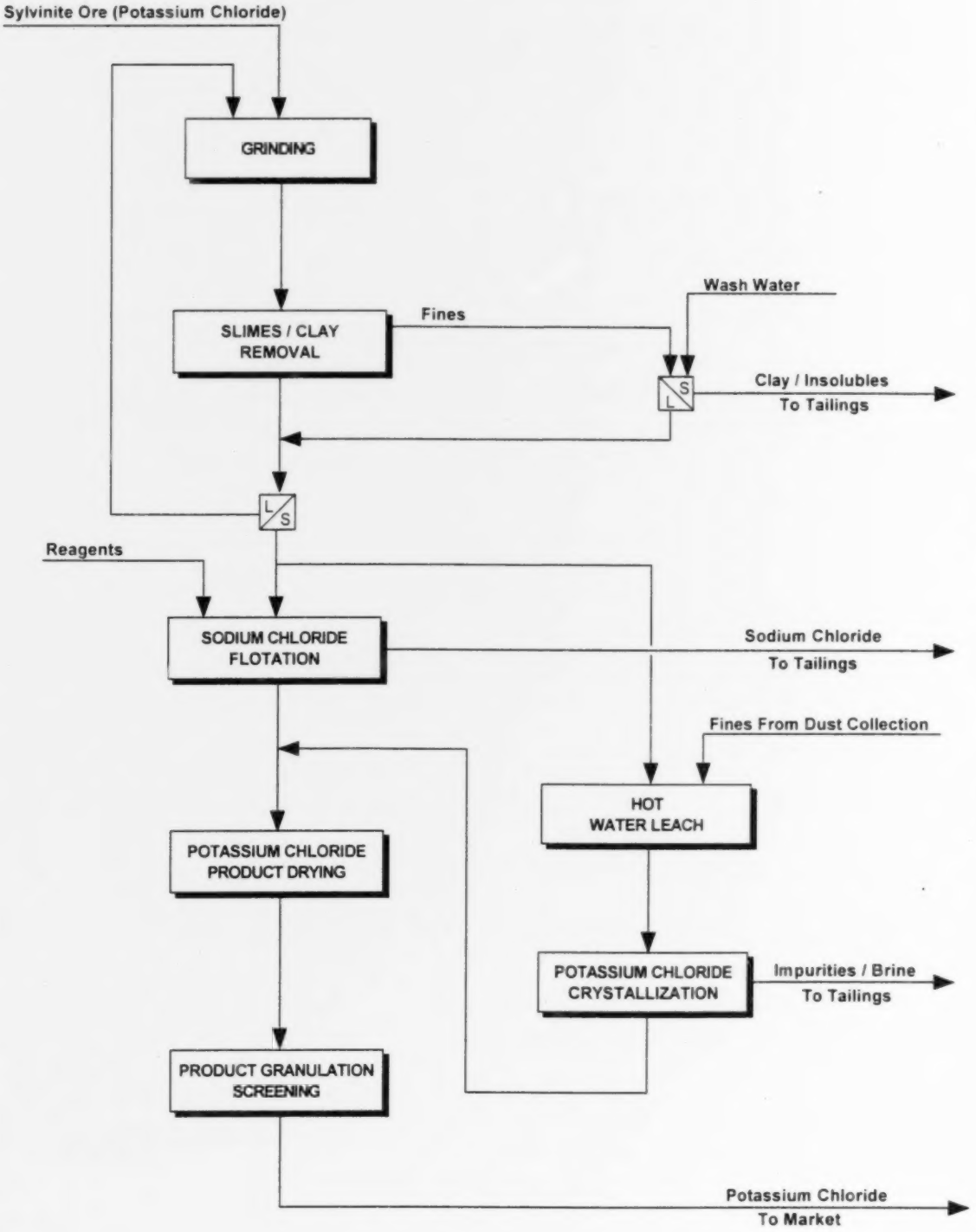
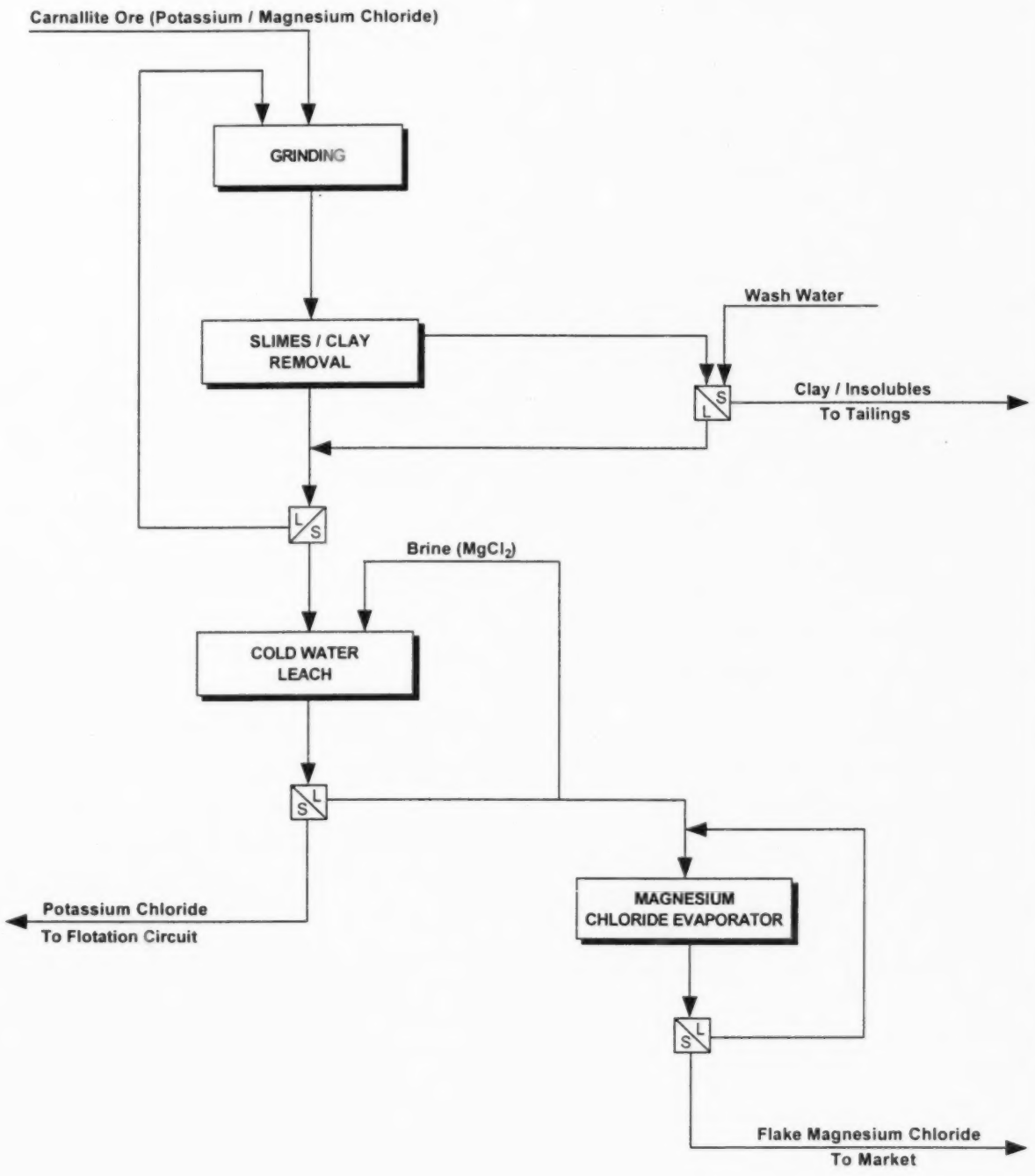
APPENDIX I

BLOCK DIAGRAMS - ORE PROCESSING

DEPARTMENT OF NATURAL RESOURCES AND ENERGY



Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Potassium Chloride / Sylvinite Ore Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No: 6525-BD-1000-001	Drawing Status: For Information Only	Revision: 00A

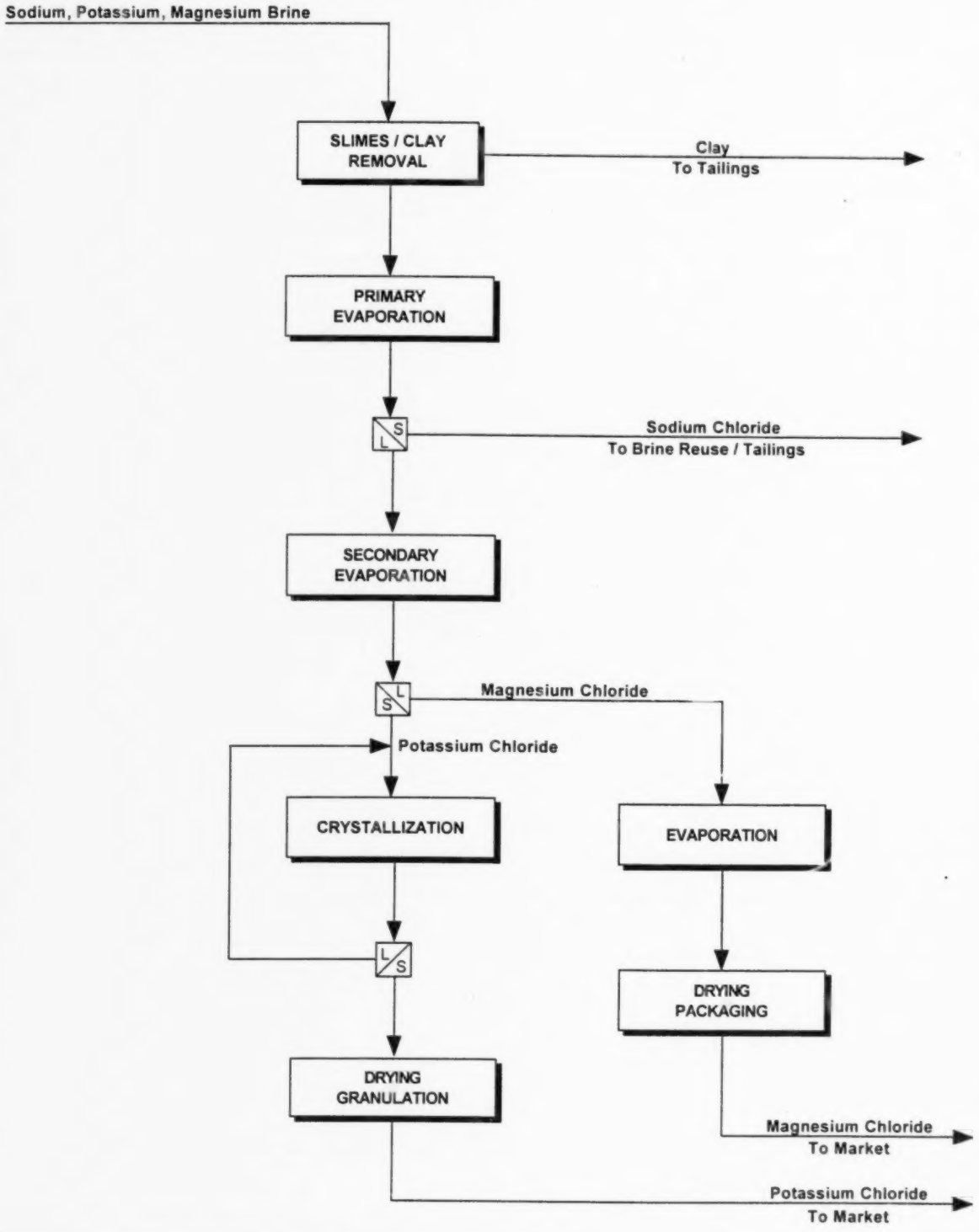


Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Potassium / Magnesium Chloride / Carnallite Ore Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No. 6525-BD-1000-002	Drawing Status: For Information Only	Revision: 00A

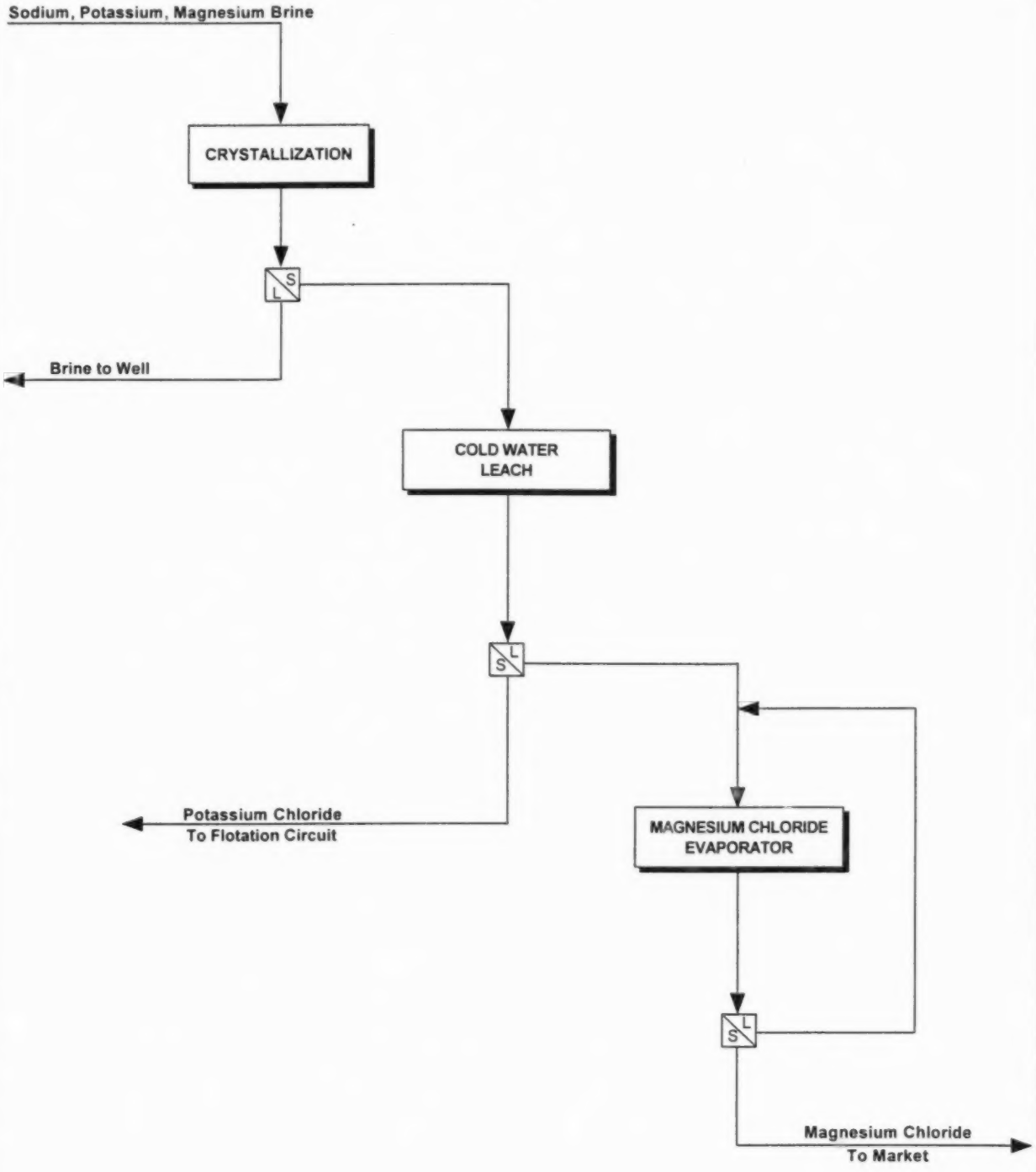
APPENDIX II

BLOCK DIAGRAMS - BRINE TREATMENT PROCESS TECHNOLOGIES

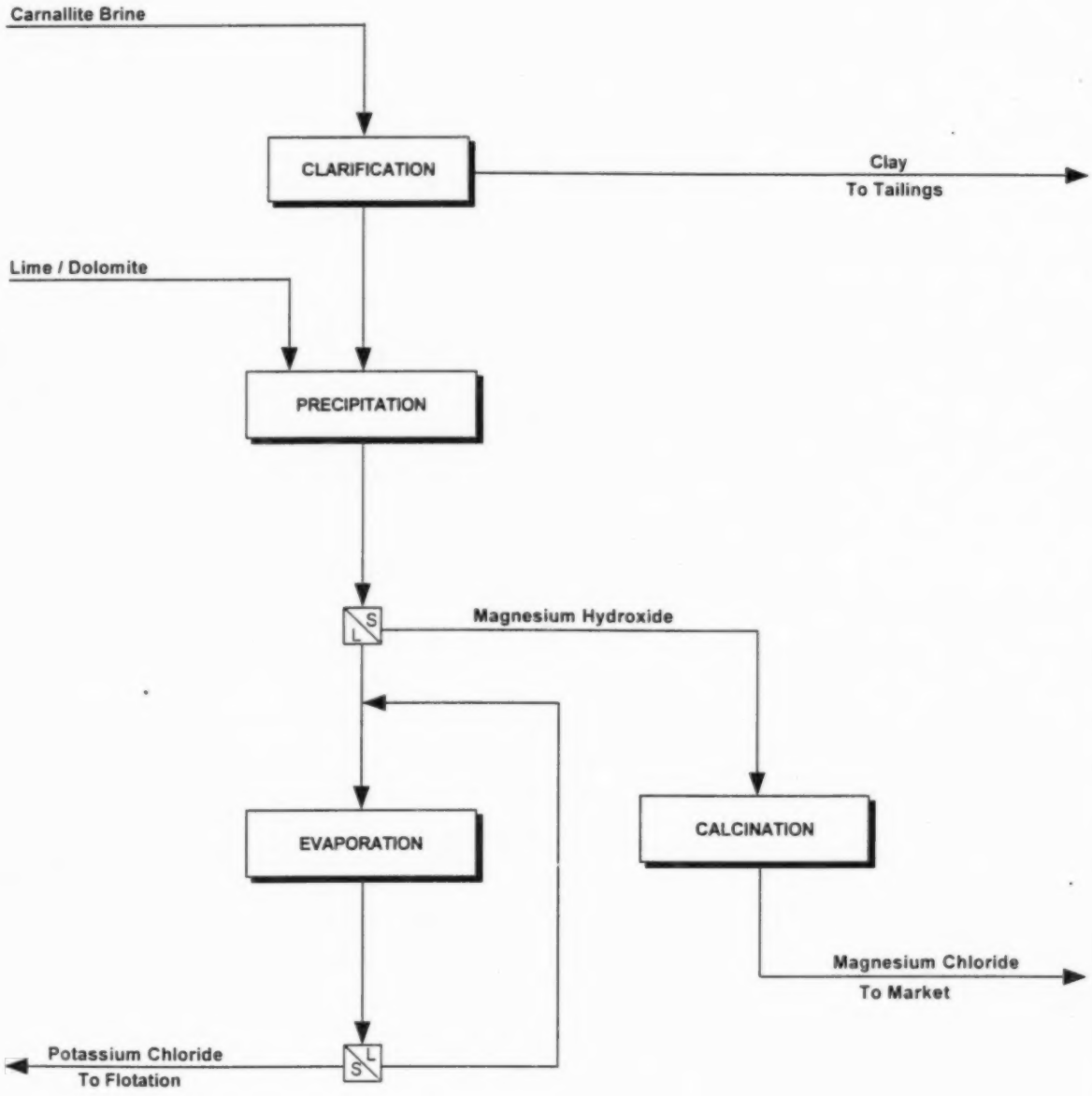
DEPARTMENT OF NATURAL RESOURCES AND ENERGY



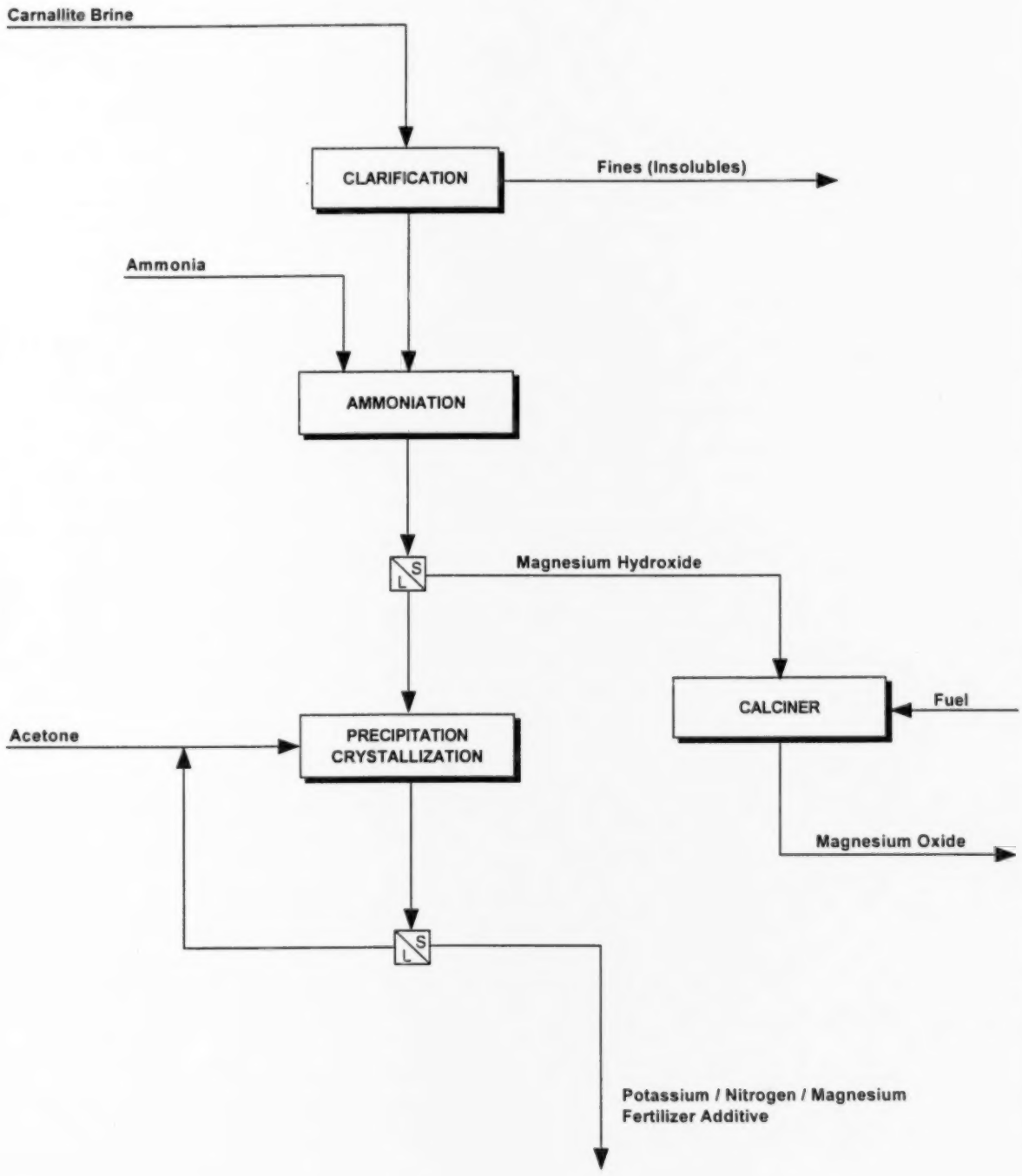
Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Brine Evaporation / Crystallization Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No: 6525-BD-2000-001	Drawing Status: For Information Only	Revision: 00A



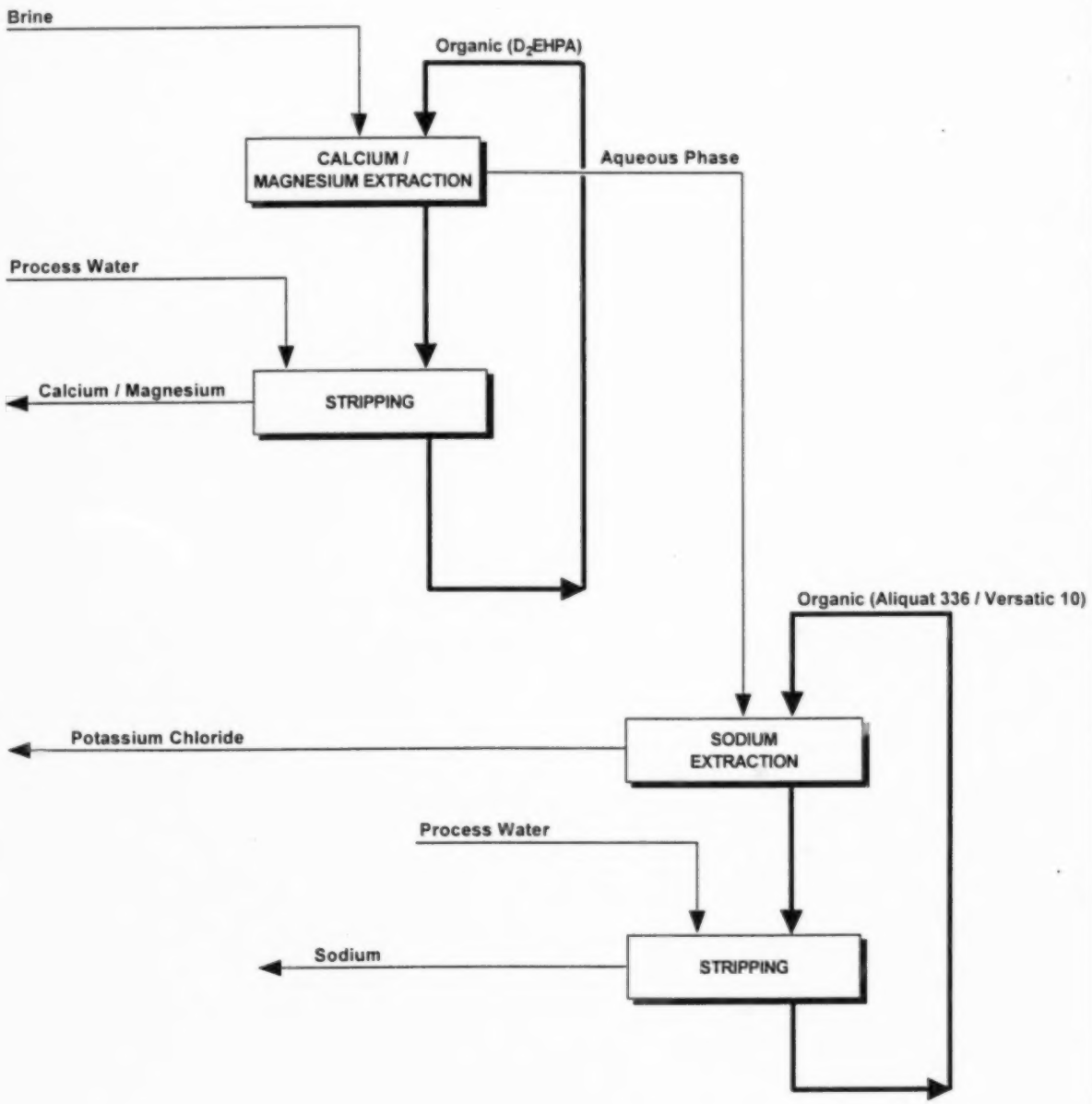
Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Hot Brine Crystallization Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No.: 6525-BD-2000-002	Drawing Status: For Information Only	Revision: 00A



Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Magnesium Hydroxide Precipitation Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No.: 6525-BD-2000-003	Drawing Status: For Information Only	Revision: 00A



Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Ammonia Precipitation / Solvent Crystallization Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No.: 6525-BD-2000-004	Drawing Status: For Information Only	Revision: 00A

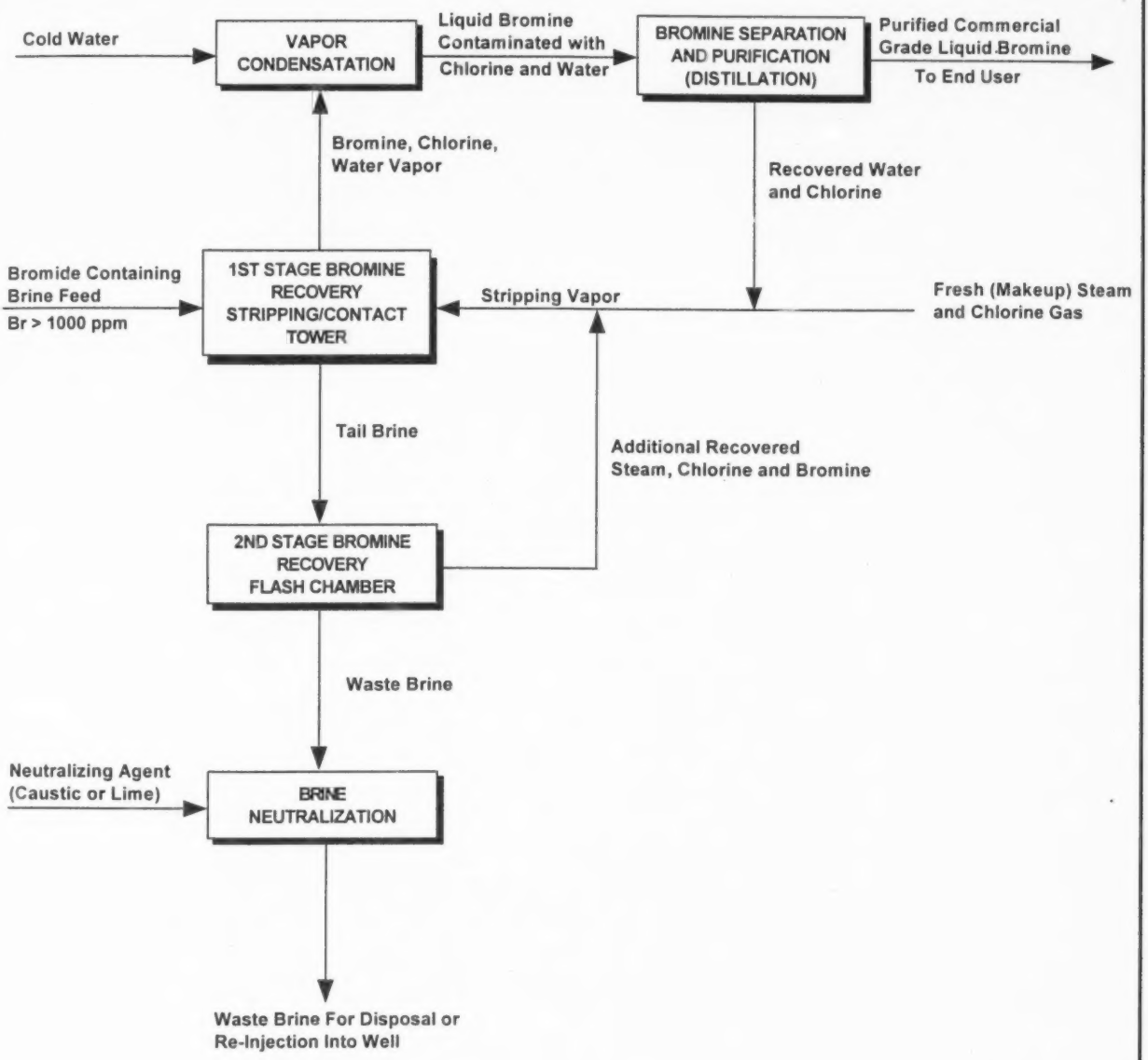


Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Solvent Extraction Process		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No.: 6525-BD-2000-005	Drawing Status: For Information Only	Revision: 00A

APPENDIX III

BLOCK DIAGRAMS - CO-PRODUCTION PROCESS TECHNOLOGIES

DEPARTMENT OF NATURAL RESOURCES AND ENERGY


Cold Water
VAPOR CONDENSATATION
Liquid Bromine Contaminated with Chlorine and Water
BROMINE SEPARATION AND PURIFICATION (DISTILLATION)
Purified Commercial Grade Liquid Bromine
To End User
Bromine, Chlorine, Water Vapor
Recovered Water and Chlorine
Bromide Containing Brine Feed
Br > 1000 ppm
1ST STAGE BROMINE RECOVERY STRIPPING/CONTACT TOWER
Stripping Vapor
Fresh (Makeup) Steam and Chlorine Gas
Tail Brine
Additional Recovered Steam, Chlorine and Bromine
2ND STAGE BROMINE RECOVERY FLASH CHAMBER
Waste Brine
Neutralizing Agent (Caustic or Lime)
BRINE NEUTRALIZATION
Waste Brine For Disposal or Re-Injection Into Well

Client: DEPARTMENT OF NATURAL RESOURCES & ENERGY			Thibault & Associates Inc. Applied Process Chemical Engineering		
Project: Assessment of Process Alternatives For Millstream K/Mg Project			Title: Bromine Recovery From Brine Tailings		
Prepared by: D. Budden	Issue Date: March 31, 2003	Revision Date: March 31, 2003	Drawing No.: 6525-BD-3000-001	Drawing Status: For Information Only	Revision: 00A